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Hoshino

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(54) **MODULE BATTERY WITH MULTIPLE CELLS CONNECTED IN SERIES WITH FUSE AND METHOD OF MANUFACTURING MODULE BATTERY**

(71) Applicant: **NGK Insulators, Ltd.**, Nagoya-Shi (JP)

(72) Inventor: **Koji Hoshino**, Nagoya (JP)

(73) Assignee: **NGK Insulators, Ltd.**, Nagoya (JP)

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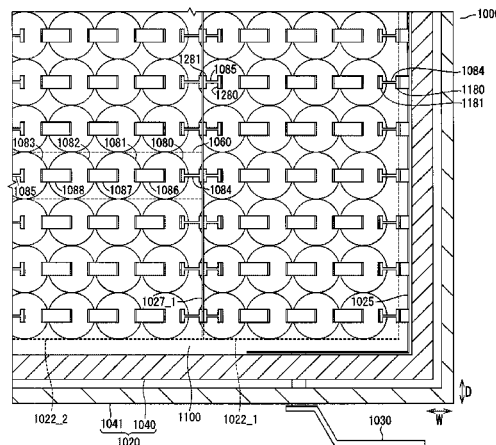
Primary Examiner — Gary Harris

(74) *Attorney, Agent, or Firm* — Burr & Brown, PLLC

(57) **ABSTRACT**

Two or more strings are connected in parallel. The strings each include two or more cells and a fuse. The two or more cells are connected in series. The fuse is connected in series to the two or more cells. Combustion of the cells do not occur when heat generated per unit time by the cells is less than or equal to an upper limit. The number of series-connected cells is determined to be less than or equal to a threshold value, within which the electric power converted into heat by a short-circuited cell in the event of a failure reaches the upper limit. The fusing current matches with a charging current that flows to a fault string when the electric power converted into heat by a short-circuited cell in the event of a failure reaches the upper limit.

2 Claims, 13 Drawing Sheets



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H01M 10/39 (2006.01)
H02H 7/18 (2006.01)
H02J 7/00 (2006.01)
- (52) **U.S. Cl.**
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2200/103 (2013.01); *H02H 7/18* (2013.01);
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2200/00; *H02H 7/18*; *H02J 2007/0037*;
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See application file for complete search history.

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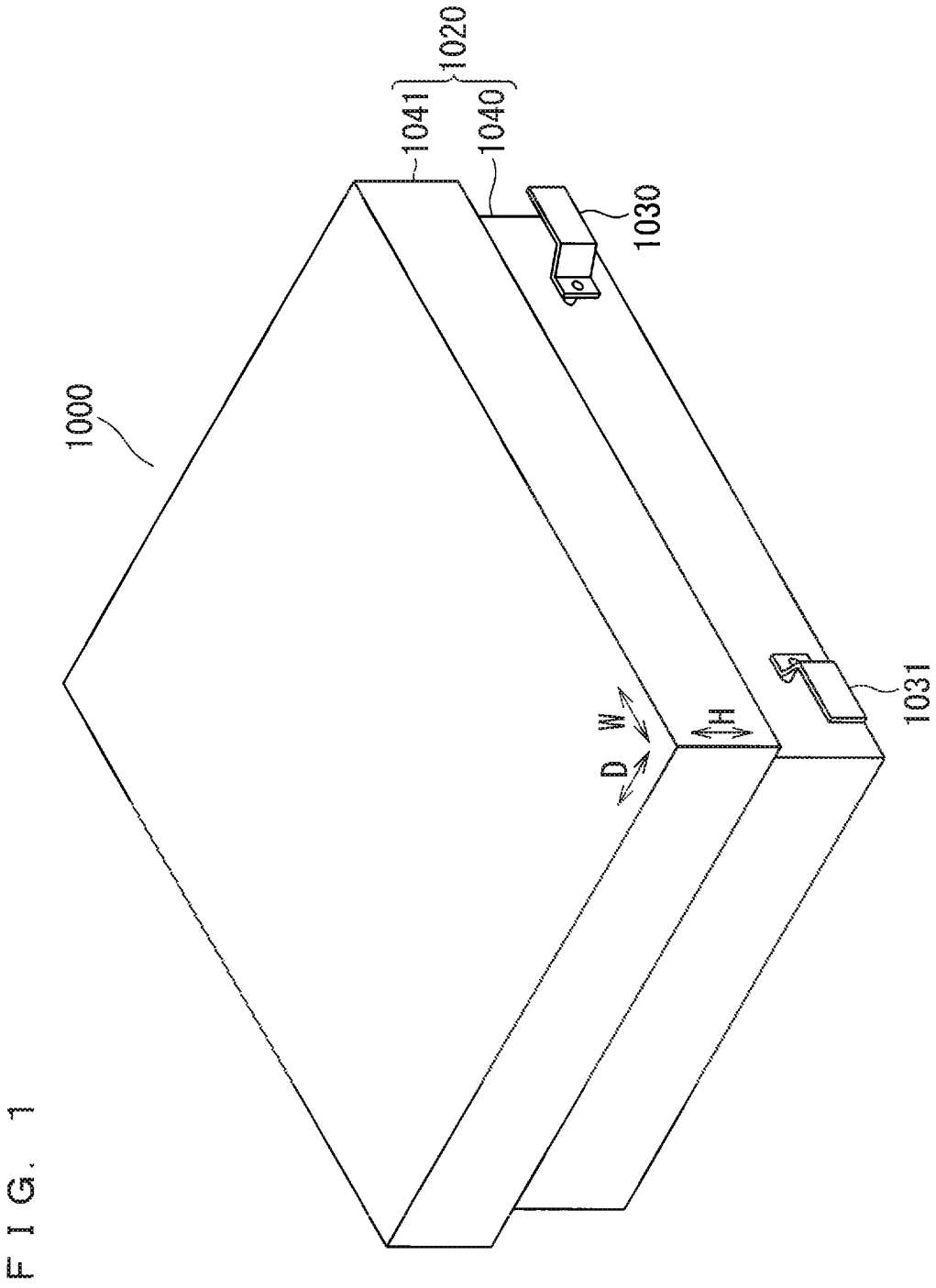
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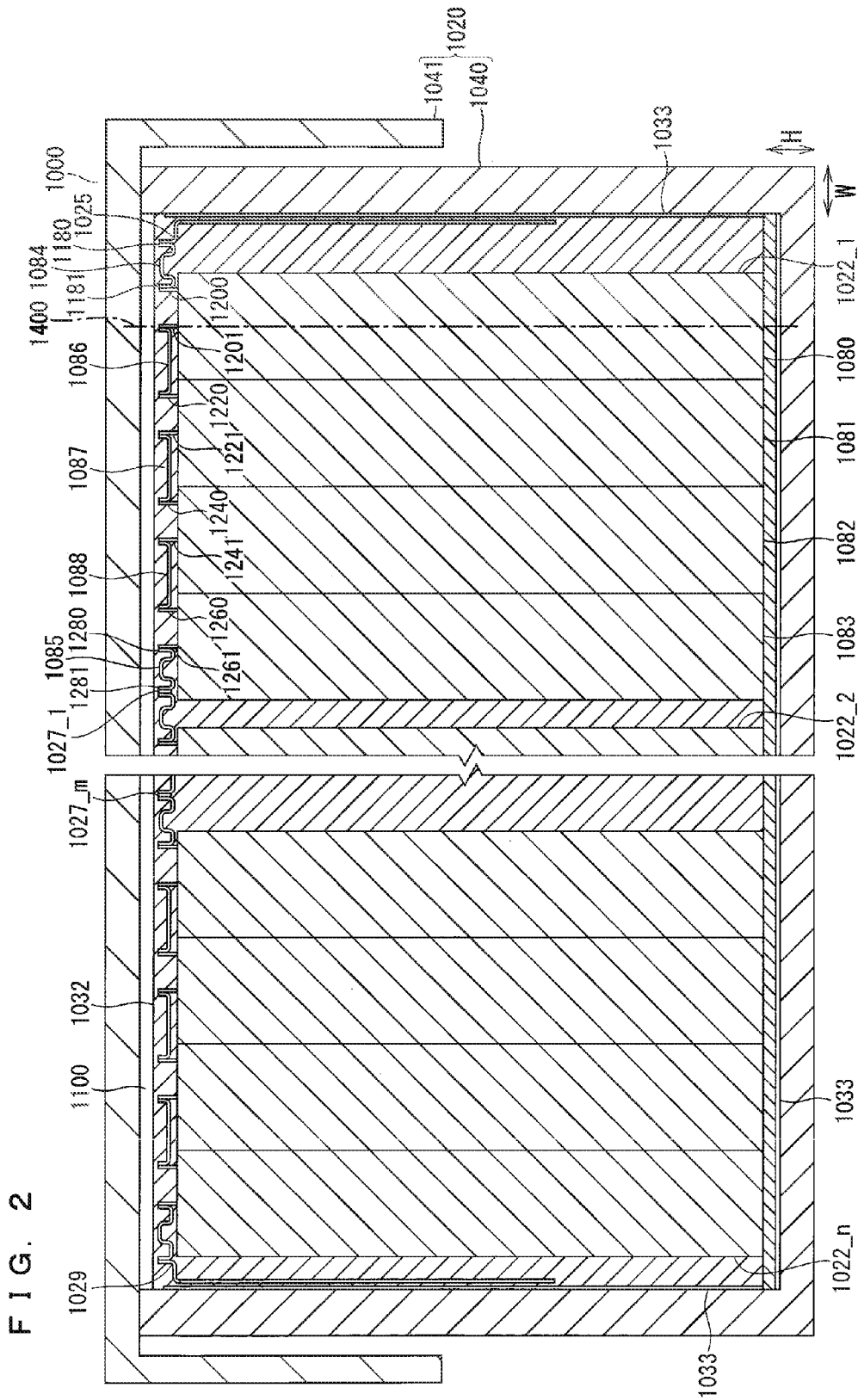
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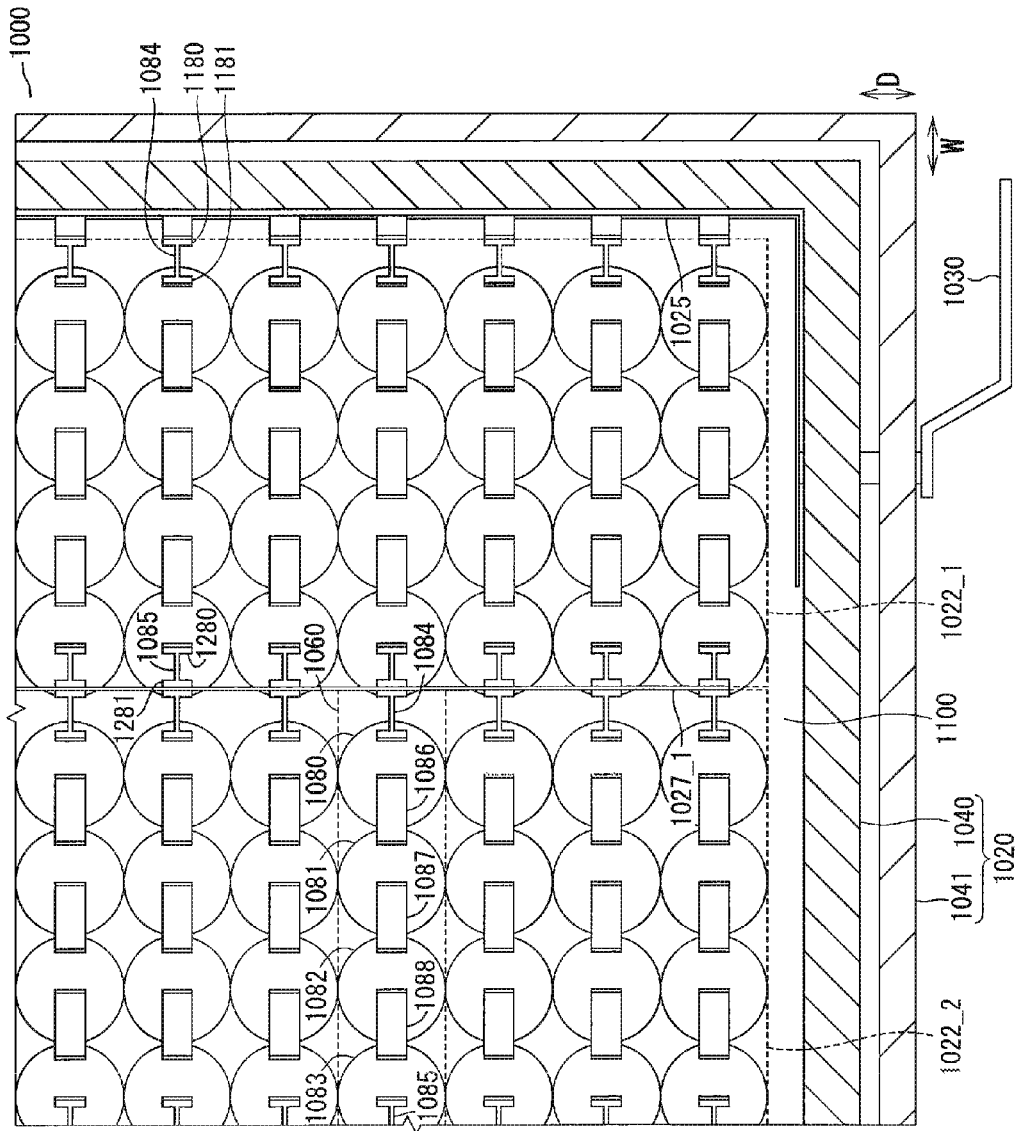


FIG. 3

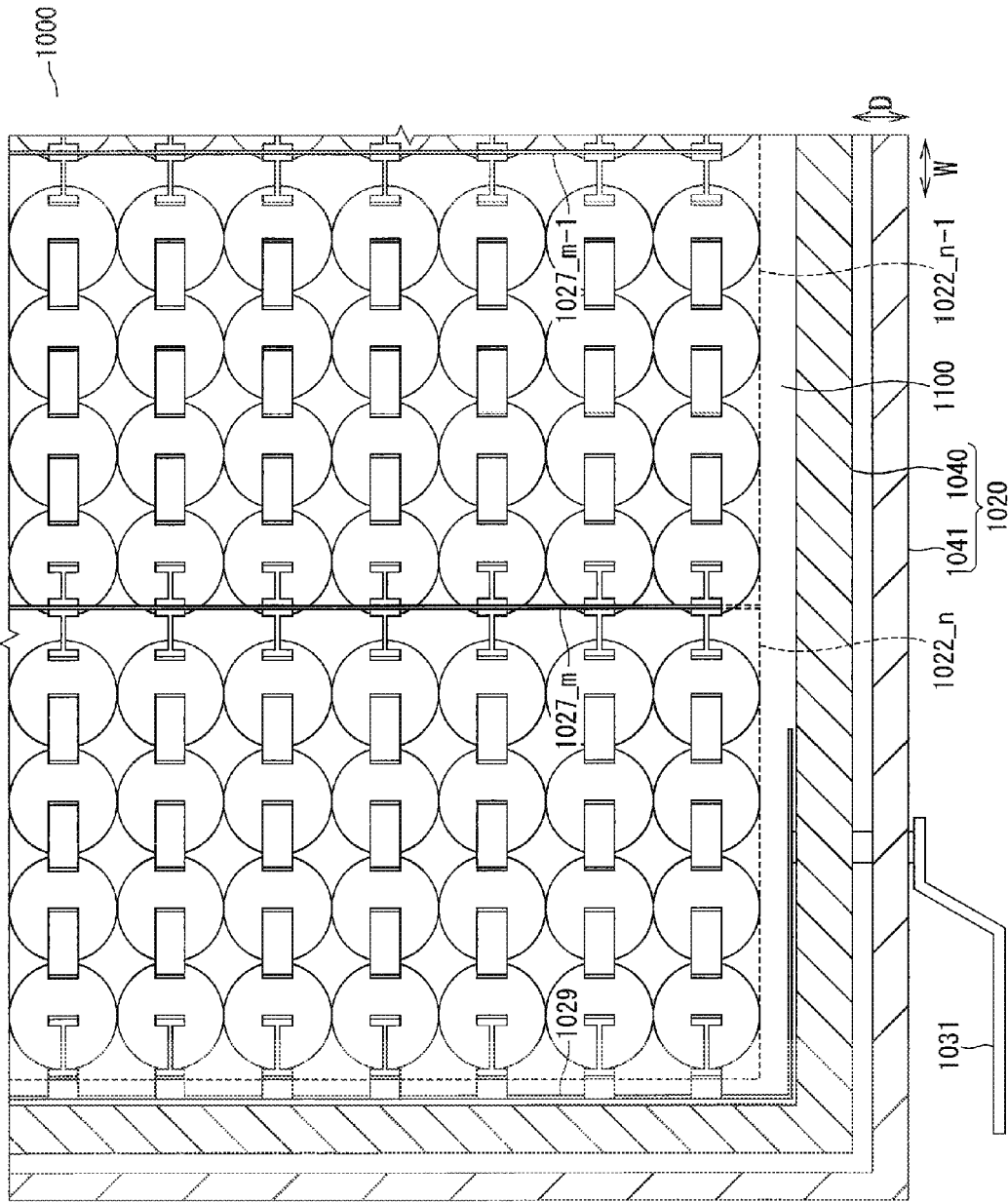


FIG. 4

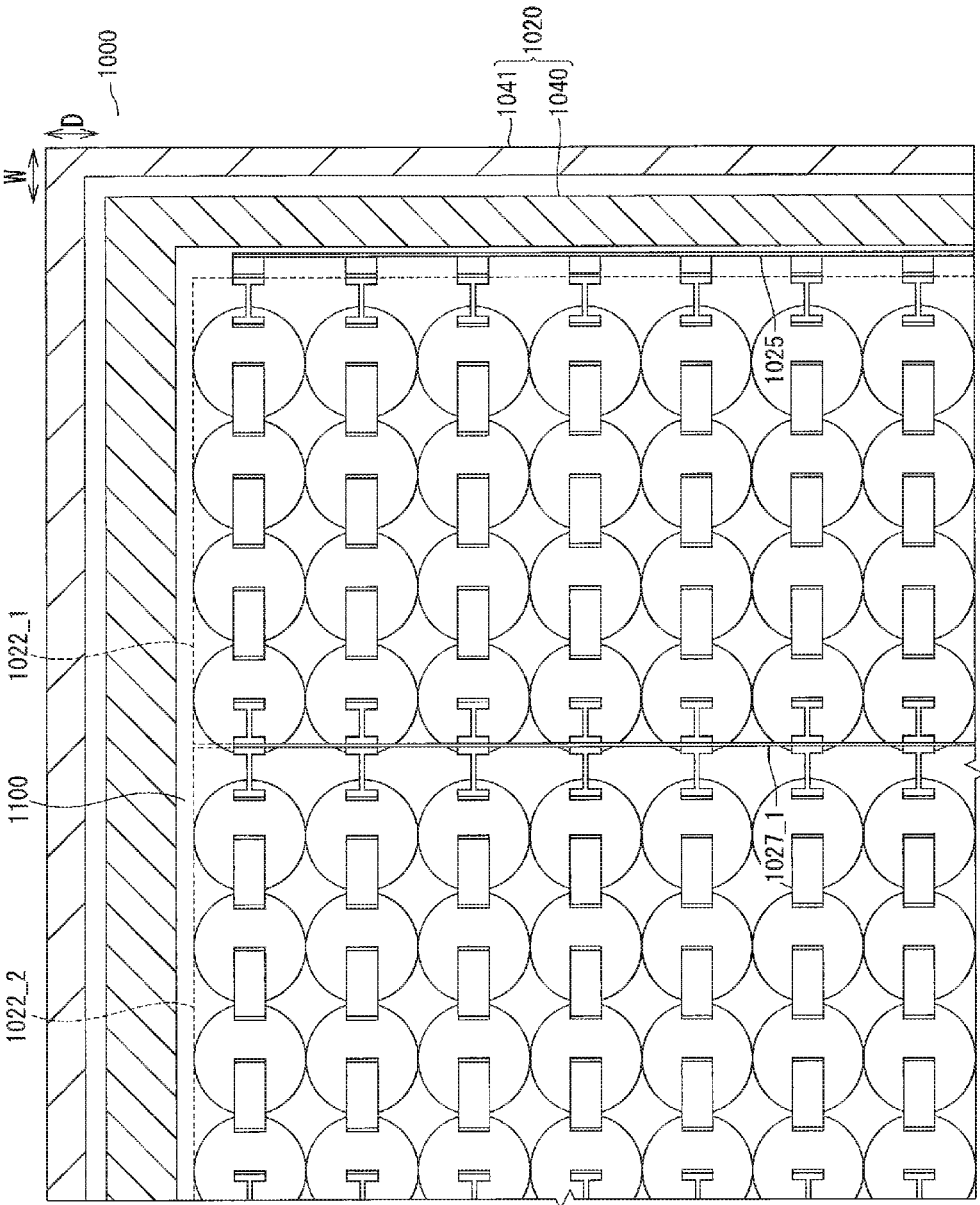


FIG. 5

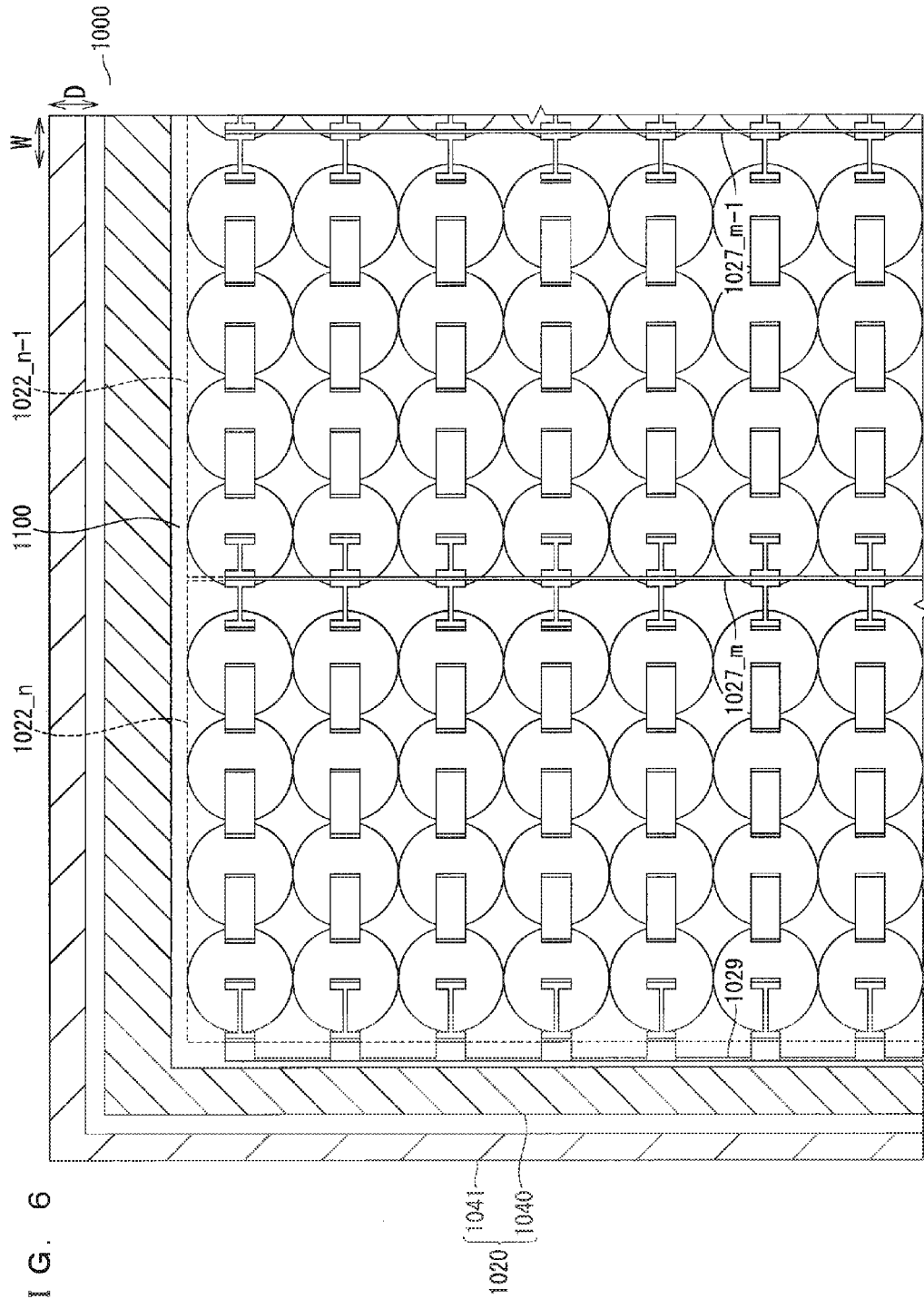


FIG. 6

FIG. 7

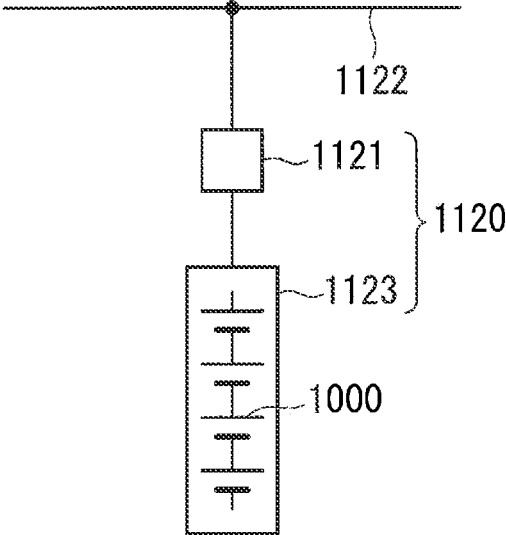
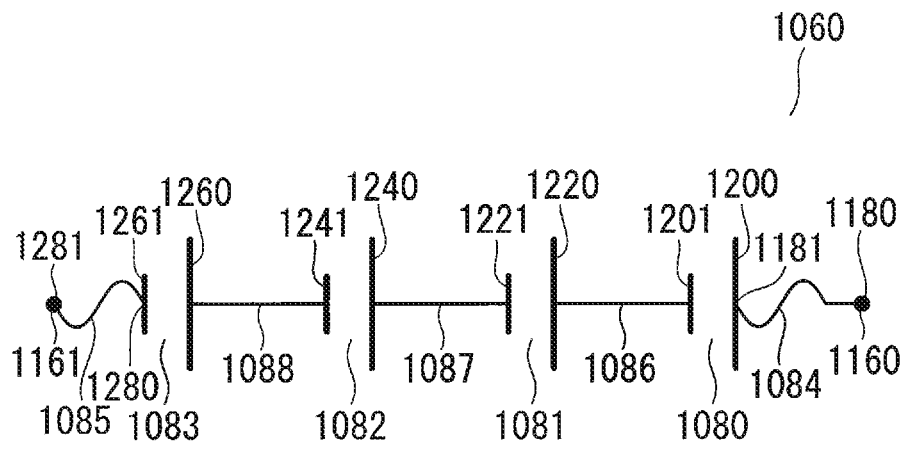


FIG. 9



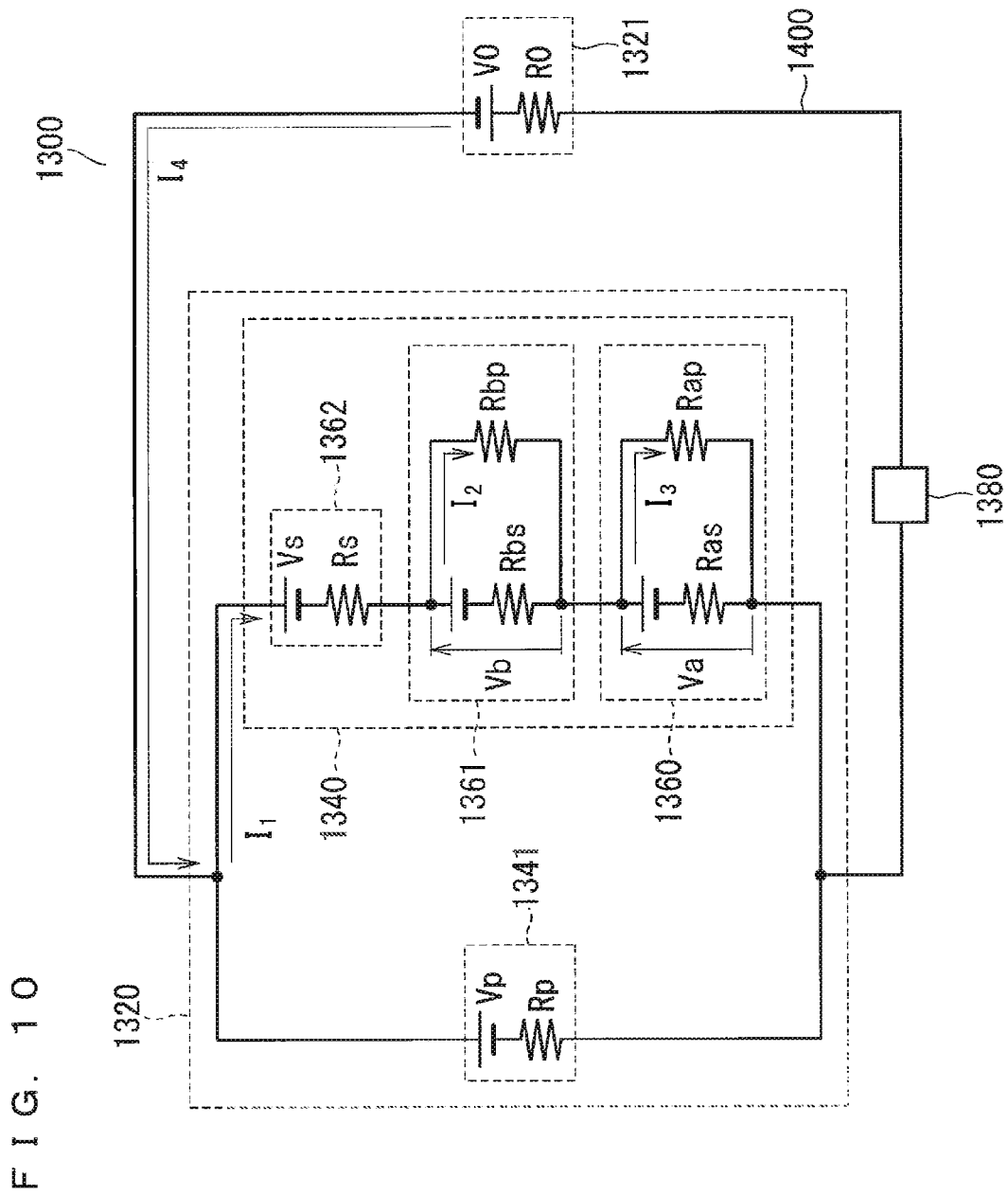


FIG. 11

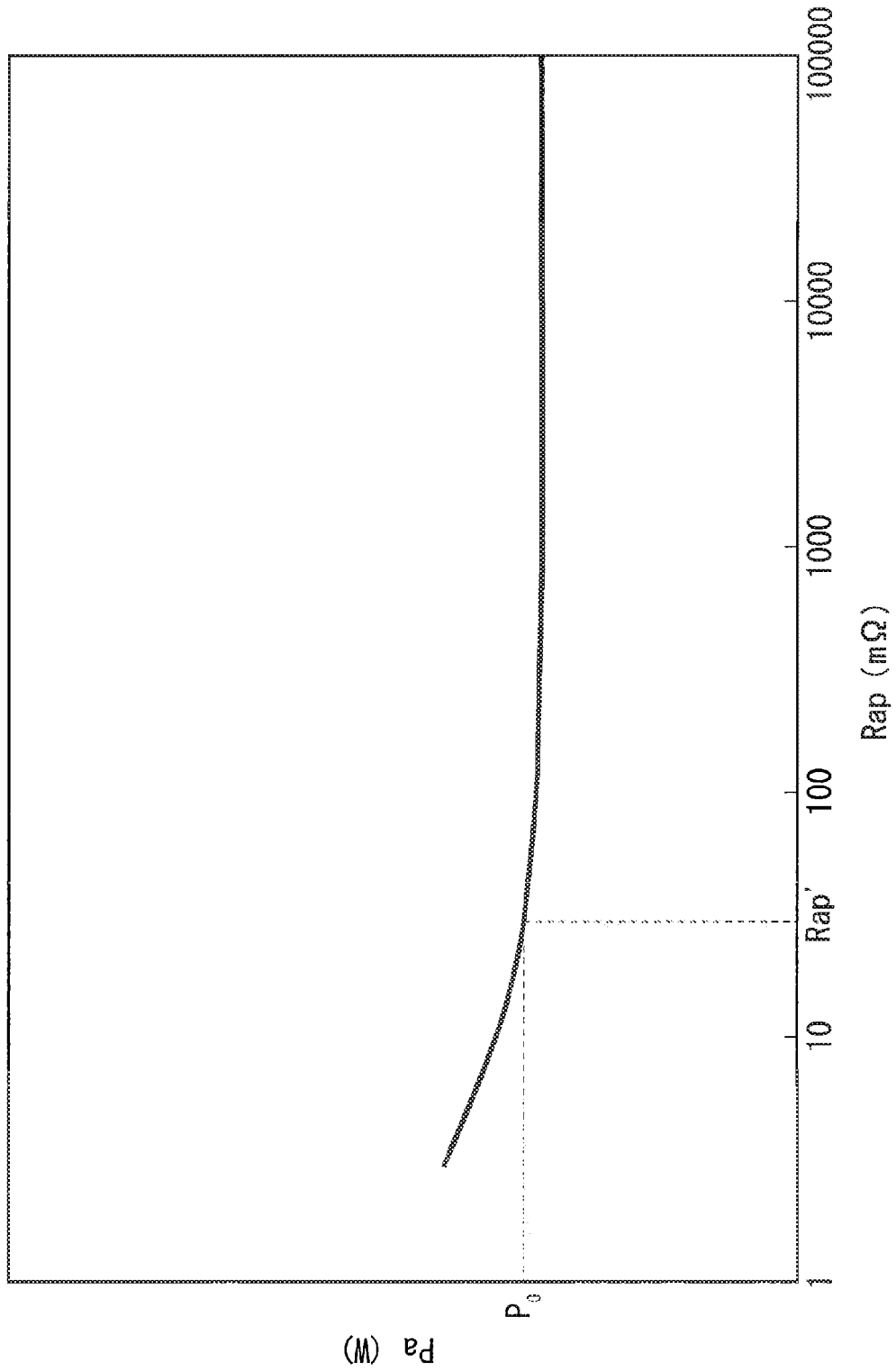


FIG. 12

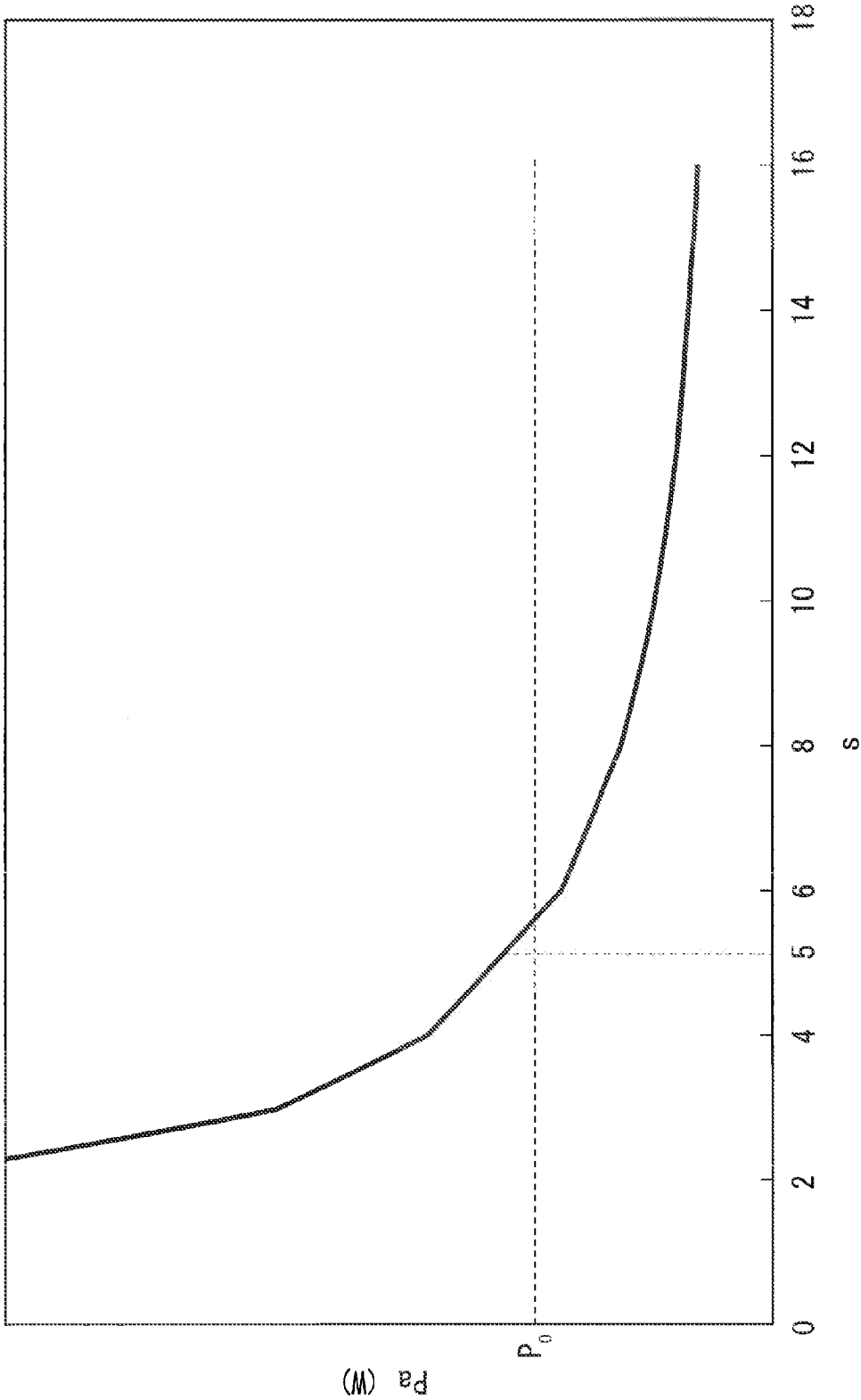
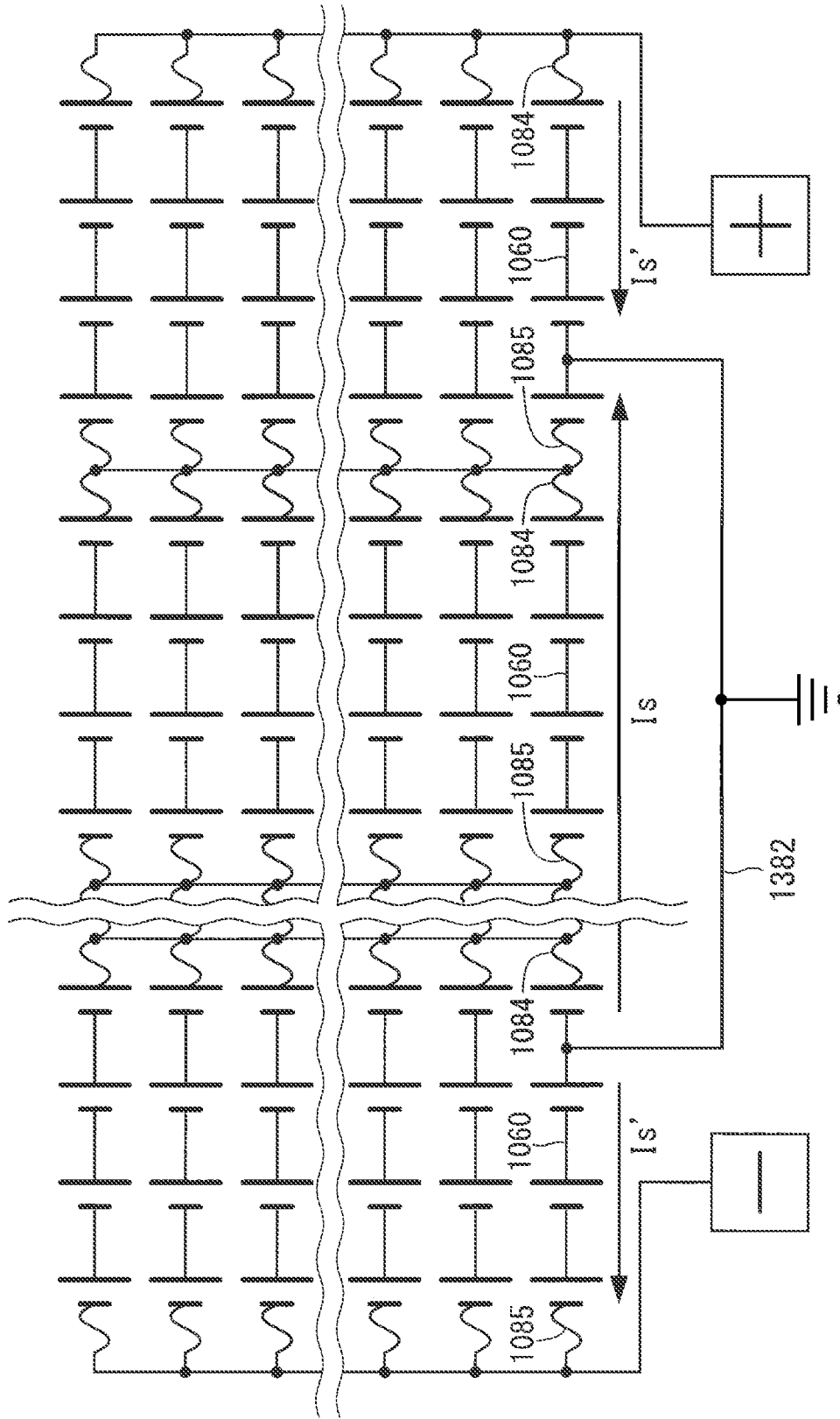


FIG. 13



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**MODULE BATTERY WITH MULTIPLE
CELLS CONNECTED IN SERIES WITH
FUSE AND METHOD OF MANUFACTURING
MODULE BATTERY**

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a module battery and a method of manufacturing the module battery.

2. Description of Related Art

Module batteries of sodium-sulfur batteries include a large number of cells connected in series and in parallel. For example, Patent Literature 1 discloses that two or more cells (electric cells **2**) connected in series form a string, two or more strings connected in parallel via a parallel bus (parallel connection bus **8**) form a block (electric cell group **16**, **17**, **18**, or **19**), and two or more blocks are connected in series. The two or more cells are connected in series to a fuse (fuse part **10b**).

Non-Patent Literature 1 mentions a desirable range of the number of series-connected cells (electric cells). According to Non-Patent Literature 1, the number of series-connected cells is desirably in the range of 5 to 10 because a high charging current (overcharging follow current) will flow to a short-circuited cell when only a small number of cells are connected in series.

PRIOR ART LITERATURES

Patent Literature

Patent Literature 1: Japanese Patent Application Laid-open No. 6-231748

Non-Patent Literature

Non-Patent Literature 1: Takashi Isozaki and four others, "Development of Sodium-Sulfur Batteries," NGK review of NGK Insulators, Ltd., No. 57A (September 1998)

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

As mentioned in Non-Patent Literature 1, a high charging current will flow to a short-circuited cell when only a small number of cells are connected in series. A small number of series-connected cells can thus easily cause combustion of a short-circuited cell, compromising the safety of the module battery.

On the other hand, a large number of series-connected cells can cause wide variations in the states of charge of individual cells in a fully-charged condition. This inhibits efficient use of the capacities of the cells, reducing the energy density of the module battery. A large number of series-connected cells also increase the number of strings that cannot be used in the event of a failure of two or more cells, thus increasing the number of times that maintenance is required for the module battery.

In other words, conventional module batteries of sodium-sulfur batteries fail to achieve the following goals at the same time: ensuring safety, improving energy density, and reducing the number of times that maintenance is required. This problem is common to all module batteries other than those of sodium-sulfur batteries.

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The present invention has been achieved in light of such a problem. An object of the present invention is to achieve the following goals at the same time: ensuring safety, improving energy density, and reducing the number of times that maintenance is required.

Means for Solving the Problems

First and second aspects of the present invention relate to a module battery.

In the first aspect of the present invention, two or more strings are connected in parallel. Each of the two or more strings includes two or more cells and a fuse. The two or more cells are connected in series, and the fuse is connected in series to the two or more cells.

The fuse is blown when a current higher than or equal to a fusing current flows.

Combustion of each of the two or more cells does not occur when heat generated per unit time by the cell is less than or equal to an upper limit.

A failure is defined as a case where the two or more strings include a fault string, and the two or more cells that belong to the fault string include a short-circuited cell.

The number of the two or more cells connected in series is determined to be less than or equal to a threshold value, within which electric power converted into heat by the short-circuited cell in the event of a failure reaches the upper limit.

The fusing current matches with a charging current that flows to the fault string when the electric power converted into heat by the short-circuited cell in the event of the failure reaches the upper limit.

The second aspect of the present invention provides an additional feature with the first aspect of the present invention. In the second aspect of the present invention, the fuse is a first fuse, and a second fuse is further provided. The first fuse is disposed further to a positive electrode side than the two or more cells. The second fuse is disposed further to a negative electrode side than the two or more cells. The second fuse is connected in series to the two or more cells and is blown when a current higher than or equal to the fusing current flows.

A third aspect of the present invention relates to a method of manufacturing the module battery.

In the third aspect of the present invention, the number of the two or more cells connected in series is determined, and the fusing current of the fuse is determined. The module battery is assembled in accordance with these determination results. The determination of the number of the two or more cells connected in series and the determination of the fusing current of the fuse are performed, following the description in the first aspect of the present invention.

Summary of the Invention

The present invention reduces variations in the states of charge of individual cells in a fully-charged condition, enables efficient use of the capacities of the cells, and improves the energy density of the module battery.

The present invention prevents the heat generated per unit time by the short-circuited cell from exceeding the upper limit and prevents combustion of the short-circuited cell, thus improving the safety of the module battery.

The present invention also inhibits an increase in the number of strings that cannot be used in the event of a failure of two or more cells, reducing the number of times that maintenance is required for the module battery.

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According to the second aspect of the present invention, it is possible to reliably block a short-circuit current. This improves the safety of the module battery.

These and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a perspective view of a module battery.

FIG. 2 is a vertical cross-sectional view of the module battery.

FIG. 3 is a horizontal cross-sectional view of the module battery.

FIG. 4 is another horizontal cross-sectional view of the module battery.

FIG. 5 is another horizontal cross-sectional view of the module battery.

FIG. 6 is another horizontal cross-sectional view of the module battery.

FIG. 7 is a schematic diagram illustrating an example of use of the module battery.

FIG. 8 is a circuit diagram of the module battery.

FIG. 9 is a circuit diagram of a string.

FIG. 10 is a circuit diagram of a model for computation of follow-current power.

FIG. 11 is a graph illustrating a relationship between short-circuit resistance and follow-current power.

FIG. 12 is a graph illustrating a relationship between the number of series-connected cells and follow-current power.

FIG. 13 is a circuit diagram of a module battery that includes a ground-fault circuit.

DETAILED DESCRIPTION OF THE INVENTION

(Overview)

A desirable embodiment described below relates to a module battery of sodium-sulfur batteries.

A schematic diagram of FIG. 1 is a perspective view of the module battery. A schematic diagram of FIG. 2 is a vertical cross-sectional view of the module battery. Schematic diagrams of FIGS. 3 to 6 are horizontal cross-sectional views of the module battery. FIGS. 3 to 6 illustrate the module battery excluding sand and a heater, which will be described later. FIGS. 3 to 6 respectively illustrate the right front side, left front side, right back side, and left back side of the module battery.

As illustrated in FIGS. 1 to 6, a module battery 1000 includes a case 1020, n string groups 1022_1, 1022_2, . . . , and 1022_n, a positive bus 1025, in parallel buses 1027_1, 1027_2, . . . , and 1027_m, a negative bus 1029, a positive bus bar 1030, a negative bus bar 1031, sand 1032, and a heater 1033. The number n of string groups included in the module battery 1000 is two or more. Alternatively, the number n of string groups included in the module battery 1000 may be one. The number m of parallel buses included in the module battery 1000 increases or decreases depending on the number n of string groups included in the module battery 1000.

The case 1020 includes a vacuum insulation container 1040 and an atmospheric insulation lid 1041.

Each of the n string groups 1022_1, 1022_2, . . . and 1022_n includes p strings 1060. The number p of strings 1060 included in each of the n string groups 1022_1, 1022_2, . . . , and 1022_n is two or more.

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Each of the npx strings 1060 includes a first cell 1080, a second cell 1081, a third cell 1082, a fourth cell 1083, a first fuse 1084, a second fuse 1085, a first cell connector 1086, a second cell connector 1087, and a third cell connector 1088. The number of cells included in each of the npx strings 1060 may increase or decrease. More commonly, each of the npx strings 1060 includes two or more cells.

The module battery 1000 may additionally include constituent elements other than those described above. There are also cases where some of the above-described constituent elements are omitted from the module battery 1000.

The case 1020 forms an accommodation space 1100. The n string groups 1022_1, 1022_2, . . . , and 1022_n, a major part of the positive bus 1025, the m parallel buses 1027_1, 1027_2, . . . , and 1027_m, a major part of the negative bus 1029, the sand 1032, and the heater 1033 are housed in the accommodation space 1100. Alternatively, the case 1020 may be replaced by another constituent element that is hard to be called a case, and such a constituent element also forms an accommodation space similar to the accommodation space 1100.

In the case of charging the module battery 1000, a charging current flows from the positive bus bar 1030 through the interior of the module battery 1000 to the negative bus bar 1031 so that the first cells 1080, the second cells 1081, the third cells 1082, and the fourth cells 1083 are charged.

In the case of discharging the module battery 1000, a discharge current flows from the negative bus bar 1031 through the interior of the module battery 1000 to the positive bus bar 1030 so that the first cells 1080, the second cells 1081, the third cells 1082, and the fourth cells 1083 are discharged.

If an excessive charging current flows to a string 1060 to which a short-circuited cell belongs, both or either of the first fuse 1084 and the second fuse 1085 are blown, and accordingly, no charging current flows to the string 1060 including the short-circuited cell. This inhibits combustion of the short-circuited cell.

The first cell 1080, the second cell 1081, the third cell 1082, and the fourth cell 1083 are all sodium-sulfur batteries. In the case of charging or discharging the module battery 1000, the temperature of the accommodation space 1100 is adjusted by the heater 1033 to a temperature at which the sodium-sulfur batteries operate. For example, the temperature of the accommodation space 1100 is adjusted to approximately 300° C. The sodium-sulfur batteries may be replaced by other types of secondary batteries.

(Example of Use of Module Battery)

A schematic diagram of FIG. 7 illustrates an example of use of the module battery.

As illustrated in FIG. 7, the module battery 1000 is typically used in a power storage device 1120. In the case of using the module battery 1000 in the power storage device 1120, two or more module batteries 1000 are connected in series, and a series-connected body 1123 that includes the two or more module batteries 1000 is connected to a power system 1122 via an AC-DC converter (PCS) 1121. It is also possible to use the module battery 1000 for other applications.

(Connection of Strings)

FIG. 8 is a circuit diagram of the module battery.

As illustrated in FIGS. 2 to 6 and FIG. 8, a positive terminal 1160 of each of the p strings 1060 that belong to the first string group 1022_1 disposed furthest to the positive electrode side is connected to the positive bus 1025. A negative terminal 1161 of each of the p strings 1060 of the

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first string group **1022_1** is connected to the first parallel bus **1027_1**. The p strings **1060** of the first string group **1022_1** are connected in parallel via the positive bus **1025** and the first parallel bus **1027_1**, forming a first block. A current when flowing through the first block is divided into the p strings **1060** of the first string group **1022_1**.

If an integer i is in the range of 2 to $n-1$, the positive terminal **1160** of each of the p strings **1060** that belong to the i th string group **1022_i** is connected to the $(i-1)$ th parallel bus **1027_{i-1}**. The negative terminal **1161** of each of the p strings **1060** of the i th string group **1022_i** is connected to the i th parallel bus **1027_i**. The P strings **1060** of the i th string group **1022_i** are connected in parallel via the $(i-1)$ th parallel bus **1027_{i-1}** and the i th parallel bus **1027_i**, forming the i th block. A current when flowing through the i th block is divided into the p strings **1060** of the i th string group **1022_i**.

The positive terminal **1160** of each of the p strings **1060** that belong to the n th string group **1022_n** disposed furthest to the negative electrode side is connected to the m th parallel bus **1027_m**. The negative terminal **1161** of each of the p strings **1060** of the n th string group **1022_n** is connected to the negative bus **1029**. The p strings **1060** of the n th string group **1022_n** are connected in parallel via the m th parallel bus **1027_m** and the negative bus **1029**, forming the n th block. A current when flowing through the n th block is divided into the p strings **1060** of the n th string group **1022_n**.

(Connection of Buses)

As illustrated in FIGS. 3, 4, and 8, the positive bus bar **1030** is connected to the positive bus **1025**, and the negative bus bar **1031** is connected to the negative bus **1029**.

(Properties of Buses)

The buses including the positive bus **1025**, the m parallel buses **1027_1**, **1027_2**, . . . , and **1027_m**, the negative bus **1029**, the positive bus bar **1030**, and the negative bus bar **1031** are wiring structures having low electrical resistance, high mechanical strength, and high heat resistance, and they are typically plate-like or rod-like. Alternatively, all or some of the buses may be replaced by other types of wiring structures. For example, all or some of the buses may be replaced by cables.

The buses are desirably made of a metal or an alloy, more desirably, an aluminum alloy.

The connections between the strings **1060** and the buses and the connections of the buses are established by a method such as welding, swaging, or screwing that can resist high temperatures at which the sodium-sulfur batteries operate. This provides mechanical couplings between the strings **1060** and the buses and between the buses. The strings **1060** and the buses become electrically conducting, and the buses become electrically conducting.

(Connections within Strings)

A circuit diagram of FIG. 9 illustrates a string.

As illustrated in FIGS. 2 to 6 and FIG. 9, one connection terminal **1181** of the first fuse **1084** is electrically connected to a positive terminal **1200** of the first cell **1080**, which is disposed furthest to the positive electrode side. The other connection terminal **1180** of the first fuse **1084** forms the positive terminal **1160** of the string **1060**.

A negative terminal **1201** of the first cell **1080** is electrically connected to a positive terminal **1220** of the second cell **1081** via the first cell connector **1086**.

A negative terminal **1221** of the second cell **1081** is electrically connected to a positive terminal **1240** of the third cell **1082** via the second cell connector **1087**.

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A negative terminal **1241** of the third cell **1082** is electrically connected to a positive terminal **1260** of the fourth cell **1083** via the third cell connector **1088**.

A negative terminal **1261** of the fourth cell **1083**, which is disposed furthest to the negative electrode side, is electrically connected to one connection terminal **1280** of the second fuse **1085**. The other connection terminal **1281** of the second fuse **1085** forms the negative terminal **1161** of the string **1060**. The first cell **1080**, the second cell **1081**, the third cell **1082**, and the fourth cell **1083** are connected in series, and the first fuse **1084** and the second fuse **1085** are connected in series to the first cell **1080**, the second cell **1081**, the third cell **1082**, and the fourth cell **1083**. A configuration is also possible in which all or some of the first cell connector **1086**, the second cell connector **1087**, and the third cell connector **1088** are excluded, and the positive terminal of each cell is directly connected to the negative terminal of another cell. The number of series-connected cells may increase or decrease within a limiting range, which will be described later.

A current flowing to the string **1060** flows to the first fuse **1084**, the first cell **1080** the second cell **1081**, the third cell **1082** the fourth cell **1083**, and the second fuse **1085**.

(Fusing Current of Fuses)

Each of the first fuse **1084** and the second fuse **1085** is blown when a current higher than a fusing current flows.

The fusing current is determined to prevent combustion of a short-circuited cell, which is caused by electric power converted into heat by the short-circuited cell, in the event of a failure of one of the two or more strings **1060**. The first fuse **1084** and the second fuse **1085** can thus inhibit a flow of excessive charging current that can cause combustion of the short-circuited cell. This improves the safety of the module battery **1000**.

(Upper limit of Heat Generated per Unit Time)

Combustion of each of the first cell **1080**, the second cell **1081**, the third cell **1082**, and the fourth cell **1083** does not occur when the heat generated per unit time by the cell is less than or equal to an upper limit, but it may occur when the heat generated per unit time exceeds the upper limit.

Since the heat generated by the cells is Joule heat, the upper limit of the heat generated per unit time by the cells can also be the upper limit of the electric power converted into heat by the cells.

This electric power increases if charging is continued even after cells have been short-circuited. This is because electric power to be consumed by a short-circuit resistance is given by the product of a voltage applied to a cell and a current flowing to the cell, and this voltage is higher in the case of charging the cell than in the case of discharging the cell.

To prevent the combustion of cells, a failure is assumed in which the two or more strings **1060** include a fault string, and the first cell **1080**, the second cell **1081**, the third cell **1082**, and the fourth cell **1083** that belong to the fault string include a short-circuited cell. The first fuse **1084** and the second fuse **1085** inhibit a charging current from flowing to the fault string, the charging current being higher than a charging current that flows to the fault string when electric power converted into heat by the short-circuited cell in the event of a failure (hereinafter, referred to as "follow-current power") reaches the upper limit. The fusing current of the first fuse **1084** and the second fuse **1085** matches with the charging current that flows to the fault string when the follow-current power reaches the upper limit.

This prevents the heat generated per unit time by the short-circuited cell from exceeding the upper limit and

prevents combustion of the short-circuited cell, thus improving the safety of the module battery **1000**. Additionally, the first fuse **1084** and the second fuse **1085** are not easily blown because of the ordinary operating current.

(Number of Series-Connected Cells)

When a large number of cells are connected in series, the number of cells that are not short-circuited but connected in series to a short-circuited cell increases, and the internal resistances of such non-short-circuited cells limit the charging current. Thus, the follow-current power decreases as the number of series-connected cells increases. The follow-current power can reach its upper limit value when the number of series-connected cells is less than or equal to a threshold value, but it cannot reach the upper limit when the number of series-connected cells is higher than the threshold value.

A large number of series-connected cells, however, causes wide variations in the voltage of the cells in a fully-charged condition, causing wide variations in the state of charge of the cells in a fully-charged condition. This prevents efficient use of the capacities of the cells, reducing the energy density of the module battery **1000**.

In addition, a large number of series-connected cells tend to increase the number of strings that cannot be used in the event of a failure of two or more cells. This increases the number of times that maintenance is required for the module battery **1000**.

To improve energy density and reduce the number of times maintenance is required, the number of series-connected cells is set to be less than a threshold value. The safety of the module battery is ensured by the first fuse **1084** and the second fuse **1085**.

(Model for Computation of Follow-Current Power)

A circuit diagram in FIG. **10** illustrates a model for computation of the follow-current power.

As illustrated in FIG. **10**, in a model **1300** for computation of the follow-current power, one fault string **1340** that belongs to one block **1320** includes two short-circuited cells **1360** and **1361**. The model **1300** for computation of the follow-current power models a case where n is the number of blocks, p is the number of parallel-connected strings, and s is the number of series-connected cells.

The one block **1320**, a series-connected body **1321** of the remaining $n-1$ blocks, and a PCS **1380** are inserted into a charging/discharging path **1400** and the one block **1320**, a series-connected body **1321** and a PCS **1380** are connected in series. The PCS **1380** is a supply source of the charging current.

The series-connected body **1321** is assumed to be a battery that has an open-circuit voltage V_0 and an internal resistance R_0 .

In the block **1320**, the one fault string **1340** and a parallel-connected body **1341** of the remaining $p-1$ strings are connected in parallel.

The parallel-connected body **1341** is assumed to be a battery that has an open-circuit voltage V_p and an internal resistance R_p .

In the fault string **1340**, the first short-circuited cell **1360**, the second short-circuited cell **1361**, and a series-connected body **1362** of the remaining $s-2$ cells are connected in series.

The first short-circuited cell **1360** is short-circuited and has an internal resistance R_{as} and a short-circuit resistance R_{ap} . In the case of charging the module battery **1000**, a voltage V_a is applied to the first short-circuited cell **1360**, a charging current I_1 flows to the first short-circuited cell **1360**, and a current I_3 flows to the short-circuit resistance R_{ap} .

The second short-circuited cell **1361** is short-circuited and has an internal resistance R_{bs} and a short-circuit resistance R_{bp} . In the case of charging the module battery **1000**, a voltage V_b is applied to the second short-circuited cell **1361**, the charging current I_1 flows to the second short-circuited cell **1361**, and a current I_2 flows to the short-circuit resistance R_{bp} .

(Example of Determination of Fusing Current)

A graph in FIG. **11** illustrates a relationship between the short-circuit resistance R_{ap} and follow-current power P_a . The relationship in FIG. **11** is calculated using the model for computation of the follow-current power.

FIG. **11** illustrates a relationship in the case where charging energy on the alternating-current side of the PCS **1380** is 30 kW, the open-circuit voltage of the first short-circuited cell **1360** is 2.075V, the internal resistance of the first short-circuited cell **1360** is 1.15 m Ω , the open-circuit voltage of the second short-circuited cell **1361** is 1.78V, the internal resistance of the second short-circuited cell **1361** is 1.15 m Ω , the short-circuit resistance of the second short-circuited cell **1361** is 10 m Ω , and the upper limit (hereinafter, referred to as a "follow-current limit") of the heat generated per unit time by the first short-circuited cell **1360** is P_0 .

As illustrated in FIG. **11**, the follow-current power P_a decreases with increasing short-circuit resistance R_{ap} and becomes saturated.

To prevent combustion of the first short-circuited cell **1360**, the follow-current power P_a is set to not exceed the follow-current limit P_0 . For this purpose, FIG. **11** is referenced to identify a short-circuit resistance R_{ap}' at which the follow-current power P_a reaches the follow-current limit P_0 . FIG. **11** is also referenced to identify a current I_0 that is the charging current I_1 flowing when the first short-circuited cell **1360** has a short-circuit resistance R_{ap}' . The charging current I_1 less than or equal to I_0 will not cause combustion of the first short-circuited cell **1360**. The charging current I_1 higher than I_0 may cause combustion of the first short-circuited cell **1360**. The fusing current is thus set to match with I_0 .

(Example of Determination of the Number of Series-Connected Cells)

A graph in FIG. **12** illustrates a relationship between the number s of series-connected cells and the follow-current power P_a . The relationship in FIG. **12** is calculated using the model for computation of the follow-current power. The follow-current power P_a illustrated in FIG. **12** is a maximum value obtained by changing the short-circuit resistance R_{ap} .

As illustrated in FIG. **12**, the follow-current power P_a decreases as the number s of series-connected cells increases. The follow-current power P_a reaches its follow-current limit P_0 when the number s of series-connected cells is five or less. For the module battery **1000**, the number s of series-connected cells is determined to be four, which is less than or equal to the threshold value.

(Number of Parallel-Connected Strings)

The number of parallel-connected strings **1060** is desirably determined to enable efficient use of the capability of the PCS, which converts the charging current from AC to DC and converts the discharge current from DC to AC.

(Positions of Fuses)

As illustrated in FIG. **9**, in each of the strings **1060**, the first fuse **1084** is disposed further to the positive electrode side than the first cell **1080**, the second cell **1081**, the third cell **1082**, and the fourth cell **1083**, and the second fuse **1085**

is disposed further to the negative electrode side than the first cell 1080, the second cell 1081, the third cell 1082, and the fourth cell 1083.

A circuit diagram in FIG. 13 illustrates a module battery that includes a ground-fault circuit.

As illustrated in FIG. 13, in a case where the first fuses 1084 and the second fuses 1085 are disposed thus, if two strings 1060 are electrically connected to the ground and forms a ground-fault circuit 1382, the first fuse 1084 that belongs to one of the strings 1060 and the second fuse 1085 that belongs to the other string 1060 inhibit a flow of short-circuit currents Is and Is'. Accordingly, the short-circuit currents Is and Is are interrupted more reliably and the safety of the module battery 1000 is improved.

Note that the aforementioned advantage of determining the fusing current and the number of series-connected cells can be ensured even if one of the first fuse 1084 and the second fuse 1085 is omitted or even if the positions of both or one of the first fuse 1084 and the second fuse 1085 are changed.

(Fuse Length)

As illustrated in FIGS. 2 to 6, each of the first cell 1080, the second cell 1081, the third cell 1082, and the fourth cell 1083 is a cylindrical cell that has a cylindrical axis 1400 and is vertically positioned. The positive terminals 1200, 1220, 1240, and 1260 are respectively not on the cylindrical axes 1400 of the first cell 1080, the second cell 1081, the third cell 1082, and the fourth cell 1083. The negative terminals 1201, 1221, 1241, and 1261 are respectively on the cylindrical axes 1400 of the first cell 1080, the second cell 1081, the third cell 1082, and the fourth cell 1083. The positive terminals 1200, 1220, 1240, and 1260 are respectively spaced from the negative terminals 1201, 1221, 1241, and 1261 in a width direction W of the module battery 1000. More commonly, the positive terminals 1200, 1220, 1240, and 1260 are respectively spaced from the negative terminals 1201, 1221, 1241, and 1261 in a first direction that is perpendicular to the cylindrical axes 1400.

In each of the strings 1600, the first fuse 1084, the first cell 1080, the second cell 1081, the third cell 1082, the fourth cell 1083, and the second fuse 1085 are arranged in the width direction W of the module battery 1000. More commonly, they are arranged in the first direction perpendicular to the cylindrical axes 1400.

In each of the n string groups 1022_1, 1022_2, . . . , and 1022_n, the strings 1060 are arranged in a depth direction D of the module battery 1000. More commonly, the strings 1060 are arranged in a second direction that is perpendicular to both the cylindrical axes 1400 and the aforementioned first direction.

The n string groups 1022_1, 1022_2, . . . , and 1022_n are arranged in the width direction W of the module battery 1000. More commonly, the n string groups 1022_1, 1022_2, . . . , and 1022_n are arranged in the first direction perpendicular to the cylindrical axes 1400.

The one connection terminal 1181 and the other connection terminal 1180 of the first fuse 1084 are spaced from each other by the fuse length of the first fuse 1084 in the width direction W of the module battery 1000. The one connection terminal 1280 and the other connection terminal 1281 of the second fuse 1085 are spaced from each other by the fuse length of the second fuse 1085 in the width direction W of the module battery 1000.

The fuse lengths of the first fuse 1084 and the second fuse 1085 are desirably short, approximately 44 mm long. This

shortens the width direction W (first direction) of the module battery 1000, improving the energy density of the module battery 1000.

(Manufacture of Module Battery)

In the manufacture of the module battery, the number of series-connected cells and the fusing current are determined, following the above description. Then, the module battery 1000 is assembled in accordance with the determined number of series-connected cells and the determined fusing current.

While the invention has been shown and described in detail, the foregoing description is in all aspects illustrative and not restrictive. It is therefore to be understood that numerous modifications and variations can be devised without departing from the scope of the invention.

DESCRIPTION OF REFERENCE SIGNS

- 1000 Module battery
- 1022_1, 1022_2, . . . , 1022_n String group
- 1025 Positive bus
- 1027_1, 1027_2, . . . , 1027_m Parallel bus
- 1029 Negative bus
- 1060 String
- 1080 First cell
- 1081 Second cell
- 1082 Third cell
- 1083 Fourth cell
- 1084 First fuse
- 1085 Second fuse

The invention claimed is:

1. A module battery comprising:
 - two or more strings that are connected in parallel, each of said two or more strings including:
 - two or more cells that are connected only in series, said two or more cells being sodium-sulfur batteries; and
 - a fuse that is connected in series to said two or more cells and that is blown when a current higher than or equal to a fusing current flows,
 - wherein combustion of each of said two or more cells does not occur when heat generated per unit time by the cell is less than or equal to an upper limit,
 - a failure is defined as a case where said two or more strings include a fault string, and said two or more cells that belong to said fault string include a short-circuited cell,
 - the number of said two or more cells that are connected in series is determined to be less than or equal to a threshold value, within which electric power converted into heat by said short-circuited cell in the event of said failure reaches said upper limit, and
 - said fusing current matches with a charging current that flows to said fault string when the electric power converted into heat by said short-circuited cell in the event of said failure reaches said upper limit.
2. The module battery according to claim 1, wherein said fuse is a first fuse that is disposed further to a positive electrode side than said two or more cells, and each of said two or more strings further includes:
 - a second fuse that is connected in series to said two or more cells, is blown when a current higher than or equal to said fusing current flows, and is disposed further to a negative electrode side than said two or more cells.